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Renewable energies are a critical and necessary technological development deeply connected to human evolution and even survival. The extraordinary technological development of the past century brought tremendous changes to the planet which, despite the scepticism of some, are indubitably affecting the natural ecosystem and maybe even the destiny of Earth. Human evolution does not mean only advanced technological development, but also deeper consciousness and responsibility for the next generations to come. Everything on Earth exists because of the Sun: heat, wind, life... everything. Therefore, solar energy is one of the answers for renewable energy. In this thesis, the research has been conducted on polymer solar cells. In particular, the thesis deals with the extensive study of device lifetime, characterized with several methods: from bare benchmarking of the lifetimes, to more advanced characterizations of different device properties and materials under degradation. The devices were mostly produced using roll-to-roll processing, which is compatible with an upscaled production, essential for commercialization. Therefore, a fast characterization of a large number of samples has been a general goal of this thesis, which has been driving the choice of both the measurement techniques and also the methods for data handling. This included the development of both novel hardware and software. The possibility of fast screening a large number of devices can in fact lead to a faster improvement of the technology, due to the large amount of experimental data that would become available in a relatively short time. Real time in-situ data analysis, during the fabrication, is possibly the ultimate type of fast screening technique. In-situ X-ray diffraction analysis is a good example of a fast screening technique, that has been presented in this thesis. The challenge of standardizing the report of lifetime was addressed, with the development of novel methods for intercomparing the lifetime of a large amount of data. In particular, the comparison of the lifetime extracted under accelerated and outdoor conditions allowed for the generation of a tool for lifetime prediction. The lifetime extracted from outdoor conditions was found to be in between the one extracted from moderate conditions (shelf test and high temperature storage) and harsher conditions (light soaking and damp heat test). In-depth characterization techniques were also employed in order to study the effect of degradation on the device structure and its interfaces. This was done by exploiting different techniques that measured different properties of the device: mechanical, imaging, and electrical. Mechanical characterization of roll-to-roll processed samples allowed the detection of a mechanically weak interface between PEDOT:PSS and ZnO, which could be improved by applying a combination of humidity and high temperature. Moreover, impedance spectroscopy combined with modelling enabled identifying the degradation of the ZnO / active layer interface. Finally, imaging of cross sections of an ITO-free roll-to-roll processed device was performed successfully using transmission electron microscopy. The cross sections were prepared both with focused-ion-beam and ultramicrotomy, which gave the possibility for effectively comparing these two techniques. Moreover, the sectioning of the solar cells with a diamond blade, in the ultramicrotomy, opened the possibility for a fast cross sections preparation. An optimal lifetime characterization, producing relevant data for the whole OPV field, both on the macroscopic and on the microscopic level, in a fast and automatic way, is possibly the perfect lifetime characterization. The extensive characterization of lifetime performed in this thesis was done with the attempt to approach to such an optimal characterization, providing valuable results to study the effect of degradation and also providing effective tools for increasing the lifetime data exchange within the OPV research field.

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